EFFECT OF CENTRAL PILE IN INCREASING THE BEARING CAPACITY OF BORED PILE GROUPS

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ABSTRACT: The base resistance of smooth model pile groups in sand under static loading is investigated experimentally in a pile soil test apparatus. The study investigated the design of the pile foundation to support heavy structures - especially bridges for highways and railways - in the Sahara, which contains many dunes of loose to medium sand in different levels, where the foundation is supposed to be piles. In this case, cased (cast in-situ) bored piles are more economical than uncased piles. Improvement was made to the sand around the piles in order to increase the shaft resistance of the piles in the groups, and also base resistance especially for the central pile in pile groups. The study shows the effectiveness of improving the sand around the piles in increasing the bearing capacity of the pile group and increasing the bearing capacity with increasing embedment length of piles in the group. The study outlines the behaviour of 9-pile groups arranged in a doubly symmetric [square] layout with different embedment lengths and pile spacing in medium dense dry sand [normal] and dense dry sand [compacted] around the piles.

Keywords – base resistance – bored pile group - 9-pile groups - model pile groups – central pile

INTRODUCTION

When taking into account the interaction between the pile and the surrounding soil and the influence of the interaction on the pile load bearing capacity. It is well known that a great emphasis is laid these years on the investigation of point resistance and skin friction, their ratio and the factors influencing this ratio. The majority of theories consider the soil as a continuous elastic material. The theories suppose the angle of shear resistance and cohesion to be constant independent of the stresses and stress condition. For driven pile the value of the point resistance and the depths where it is reached depend significantly on the initial soil compactness, this depth amounted to (8 - 10) times the diameter for solid piles [1]. During applying load on the pile the soil gets deformed and the density considerably increases in the vicinity of pile, at the beginning of loading only the soil under the point gets compacted, while the soil at the shaft yields. The depth of the compacted zone below the tip was obtained by Kerisel (1964) and further data have been published by Grigoryan (1967) and by Koizumi (1971) as shown in figure (1).

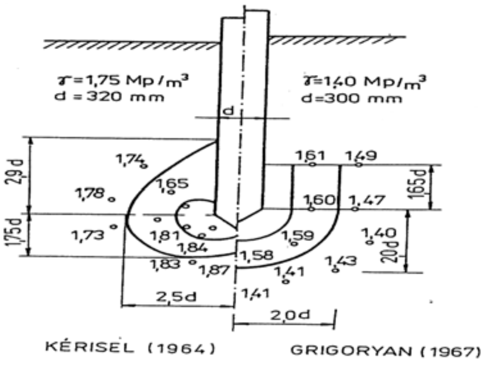

FIG.1. Depth of the compacted zone below the base [Petrazovits]

It is well known that the applied technology has a major influence on the load bearing capacity and on the interaction between the soil and the pile. Depending on the selection or execution of the construction technology, the bearing capacity of foundation engineering structure might vary considerably even in case of uniform soil. The effect of technology is extremely significant in case of deep foundation both on the load bearing capacity and on the settlement of deep foundation [2]. The type of interaction can be seen in figure (2).

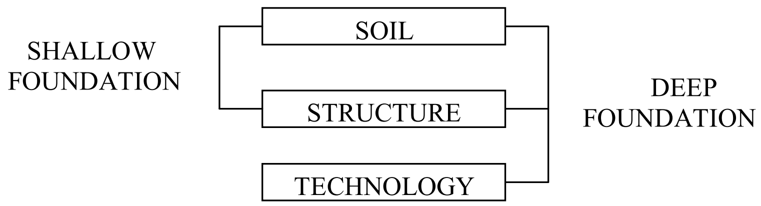

FIG.2. Type of interaction

Field tests are very expensive, and also the rather long time required to obtain reliable final settlement values limits their use. In addition, bearing capacity results from just a few loading tests are insufficient since soil conditions vary and the scatter in the bearing value is high. Therefore, carefully conducted and well documented laboratory tests have to be preferred, they may serve to reveal and evaluate the main features of the problem [1].

TEST APPARATUS

To simulate the point resistance under the pile base of model pile groups in different densities of dry sand around the piles. Tests were carried out on a smooth model pile groups 400 mm lengths and 36 mm in diameters which were built in the testing tank 1.20 m high by 1.20 m square, one side of the tank was removable as shown in figure (3). The axial load on the smooth model pile groups was measured by means of a load cell seated on pile cap, while the axial displacement was measured using a three dial gages. The used piles had smooth surfaces to minimize it's shaft friction as possible as we can to behave as bored piles executed in-situ by casing. All piles were provided with a base load cell measuring the point resistance and located at least 0.70 m from the base of the sand tank. The used coarse well graded homogenous sand was in a dry state with uniformity coefficient of CU = 2.8. The physical properties of the sand are shown in the Table .1.

EXPERIMENTAL WORKS

The pile load bearing capacity calculated by using laboratory tests data is frequently much lower than the result of test loading on the site. This difference can be attributed to the changes in stress condition due to pile execution. As mentioned above that the surfaces of model piles were smooth which, were similar to in-situ conditions of bored piles in the Sahara of Libya. [3].

Table1. Physical Properties of Sand

Condition of sand	**Dry density [g/cm^3]**	**Relative density Dr [%]**	**Void ratio e**	**Internal friction angle Φ**	**Porosity n**	**Uniformity coefficient CU**
medium dense dry sand [around piles]	1.62	58	0.65	36	0.40	2.8
dense dry sand [around piles]	1.72	84	0.56	41	0.36	2.8
dense dry sand [under base]	1.75	93	0.53	43	0.34	2.8

The condition of test was imposed, the pile was free to settle as the sand was placed around it and neglecting initial residual load distribution. The cap is relatively rigid which dealing to the equal settlement of all piles in the group. The sand was deposited in 5 layers under the base of the piles and each layer was tamped by a tamper to achieve a relative density of approximately 93 %, then the piles were erected and tested in two cases. First case-the pile groups were placed and the dry sand poured around the piles without any compacting with relative density of approximately 58 % to be in the same as in-situ condition. Second case-the pile groups were placed and the dry sand poured around the piles in layers and every layer compacted by a tamper to achieve a relative density of approximately 84 %.

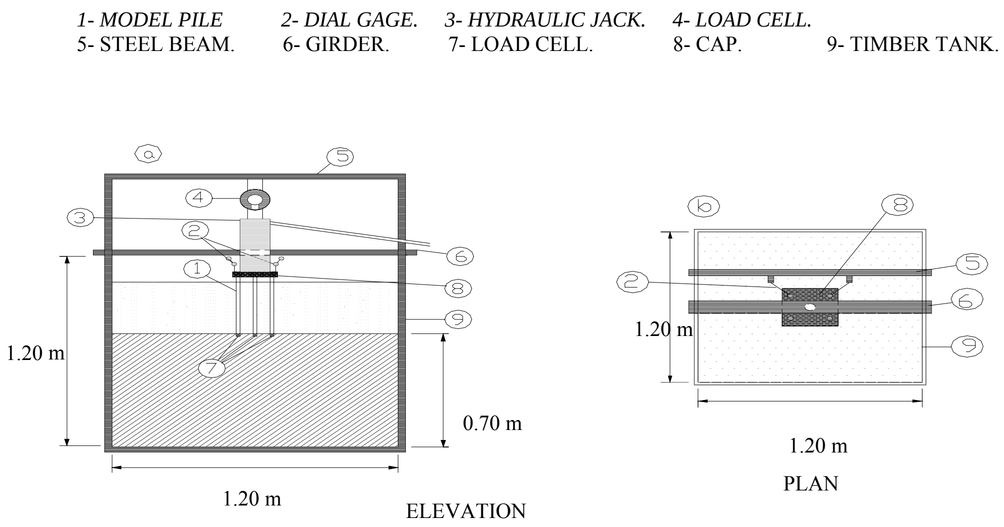

FIG.3. General details of test of apparatus [Schematic Diagram]

TEST RESULTS

The aim of the tests was to study the behaviour of individual pile in the group under axial load and the influence of central pile on the bearing capacity of bored pile groups. The variation of the magnitude of point resistance versus the embedment length. The effect of the distance between the piles. The effect of the pile embedment length. The effect of the location of the pile within the group. The twelve laboratory experiments were carried out for 9-smooth model pile groups with embedment lengths of Ld = 0.38 L, 0.65 L, 0.93 L and with pile spacing of

(S =2.5 d , S = 4.2 d) d is the diameter of the pile-in two different conditions of dry sand around the piles. During increasing the axial load, the settlement and the point resistance of the piles were measured continuously at each load step, where the skin friction was neglected. The typical load settlement curves-pile groups of smooth model piles were shown in figures (4) and (5) respectively for two cases.

Comparing the results gained from experiments on different embedment lengths and pile spacing in two soil conditions, we get:

The load bearing capacity and the settlement is more advantageous in the case of groups, where, the spacing is [s = 2.5 d] and the proportion of the central pile is bigger.

Table (2) shows that for 9- smooth model pile groups, the base resistance of the central pile to that of the corner pile is in the range (90–120) % and (30-50) % higher, for pile spacing [s =2.5d] and [s =4.2d] respectively, in the case of sand with initial relative density [Dr =0,58], whereas in the second case it is higher by (100–120) % for pile spacing [s =2.5d], and (45–95) % approximately for pile spacing [s =4.2d]..

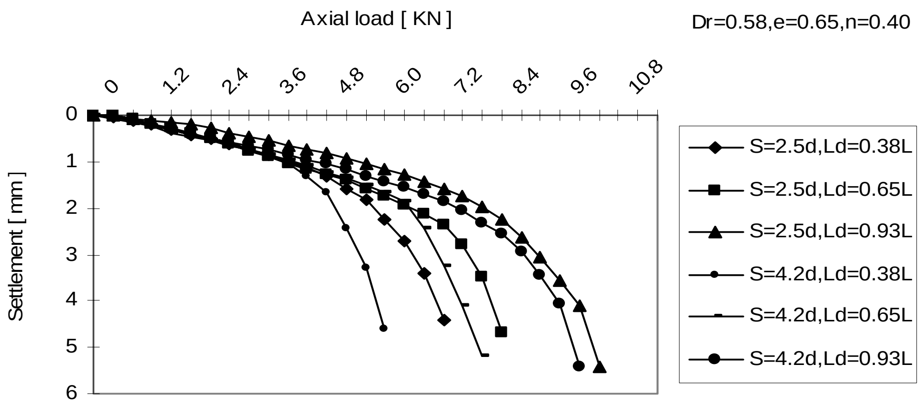

Figure 4. Typical load settlement curve of 9-smooth model pile groups [L=400 mm, D=36 mm] with different embedment pile length in medium dense dry sand

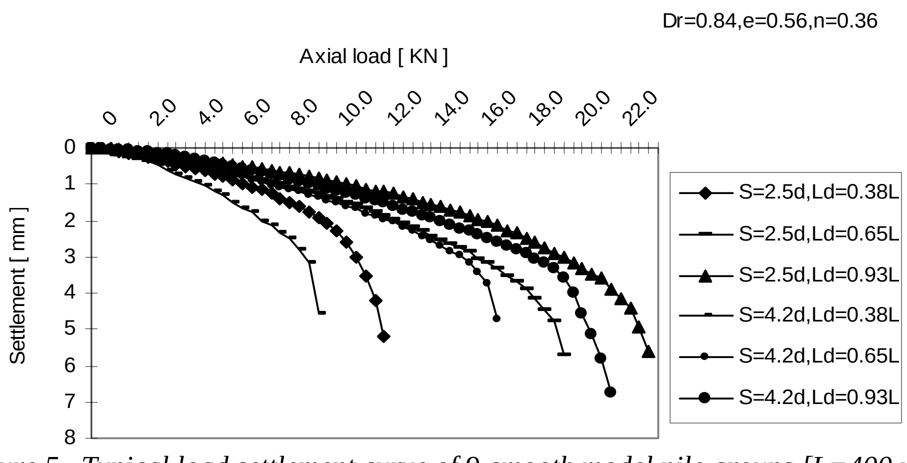

Figure 5. Typical load settlement curve of 9-smooth model pile groups [L=400 mm, D=36 mm] with different embedment pile length dense dry sand

Also, we found that the base resistance of the central pile is greater than that of the outside pile by (40–75) % and (15-25) % for pile spacing [s =2.5d] and [s =4.2d] respectively in the first case, but it is ranges (40–55) % and (25–35) % in the second case of sand around piles.

Table (3) shows that the base resistance of central pile ranges from (17–20) % of the base bearing capacity of the pile group in the first case for pile spacing [s =2.5d] and it is equal to 14 % on average for [s =4.2d], whereas in the second case, it is equal to 18 % for pile spacing [s =2.5d] and in the range (14.5–16.5) % at pile spacing [s =4.2d].

Also, we found that the average base resistance of the outside pile to the base bearing capacity of the pile groups is equal to 11.5 % approximately for two cases of soil conditions around the piles and with two different pile spacing and embedment lengths, whereas for the corner piles the proportion is equal to 8.5 % for [s =2.5d] and 10 % for [s =4.2d] in the two cases.

For 9- smooth model pile groups embedded in dry sand with [Dr =0.58, e =0.65] and [s = 2.5d] we found that the base resistance of the central pile at failure is higher than the average base resistance of the pile group by 60 % in average , whereas, the outside pile is higher by 5 %, but the corner pile is lower by 20 % approximately. In the case of pile spacing [s =4.2d] the base resistance of the central pile is higher than the average by 25 %, whereas, the outside pile is higher by 4 % and the corner pile is less than the average base resistance of the pile group by 10 %.

For 9- smooth model pile groups embedded in dry sand with [Dr =0.84, e =0.56] and [s =2.5d] the base resistance of the central pile at failure is greater than the average base resistance of the pile group by 60 % in average, but the outside pile is higher by 10 %, while the corner pile is lower by 25 % in average. However in the case of [s =4.2d] the base resistance of the central pile is on average 40 % greater than the average base resistance of the pile group, while, the outside pile is 5 % higher, and the corner pile is lower by 16 % on average.

As illustrated in tables (2) and (3) a comparison of the results gained from experiments on different embedment lengths, shows that the average failure settlement of 9- smooth model pile groups in the first case of the soil condition around the piles [Dr =0.58] is equal to [5.07 mm] for both pile spacing. Whereas, in the second case of the soil condition around the piles [Dr =0.84], the average failure settlement is equal to [5.52 mm] and [5.34 mm] approximately for pile spacing [s =2.5d] and [s =4.2d] respectively.

SUMMARY

The test apparatus described to study the behaviour of 9- pile groups of smooth model piles erected in a tank of dry sand proved to be useful tool in studying the point resistance behaviour. It offers certain features that can be advantageous in analysing the pile - soil interaction.

The results - based on the tests of 9- pile groups with different embedment lengths in coarse homogenous dry sand with different relative densities around the piles - showed that the end bearing capacity of 9- pile groups dependent on the relative density, void ratio, pile spacing and embedment length of piles.

CONCLUSION

On the basis of the tests which were done on the pile groups, the following conclusion can be made:

(1) The study shows undoubtfully that longer embedment pile lengths are advantageous in homogenous sands, especially in the case of compacted sand around piles.

(2) In the case of compacted sand around the piles the shaft friction have to be more effective in increasing the bearing capacity of pile groups.
(3) The significant increase in the load bearing capacity of central pile, increases with the decrease of the pile spacing.
(4) In the case of bigger spacing the proportion of point resistance is lower and the piles behave like single pile.
(5) The increase in bearing capacity of central pile comes from the increase of point resistance.
(6) The increase in embedment length has no settlement increasing effect.
(7) The load bearing capacity of pile groups in the second case [compacted sand around the piles] are approximately double its bearing capacity in the first case [medium dense sand around the piles]
(8) The very significant increase of point resistance in 9- smooth model pile groups - especially in the second case - is resulted by the compacted soil fenced by the corner and the outside piles and also the loading effect of the neighboring piles.
(9) The point resistance of the central pile is greater than that of the corner pile by 25 % in the case of [S = 4.2d] and 50 % in the case of [S =2.5 d] approximately.
(10) The central pile is less effectiveness in the longer pile spacing.
(11) The central pile is more effective in increasing the bearing capacity of 9-pile group in the second case [compacted sand around the piles] than that in the first case [medium dense sand] by (40 - 60) %.
(12) The total bearing capacity of pile groups with different embedment lengths at pile spacing [S =2.5d] are greater than that in the case of pile spacing [S =4.2d) by (10 - 30) % approximately.
(13) The end bearing capacity of pile groups at pile spacing [S =2.5d] are higher than that in the case of pile spacing [S =4.2d] by (15-50) %.

References

[1]. FRANKE, E. (Point Pressure versus Length and Diameter of Piles), 10 Int. Conf. on Soil Mech. and Found. Eng. Stockholm, (1981), PP. 717-722.

[2]. PETRASOVITS, G. Forming of densified zones around piles driven in sand and it's effect on bearing capacity., (6 th Conf. On Soil Mech. and Found. Eng. Budapest 1984, Geza petrasovits), PP. 187-192.

[3]. SHAHIN, M. The Behaviours of a Single Bored Pile and Pile Groups under Axial Load, Thesis for Ph.D , 1998

Table (2) The maximum base bearing capacity of individual piles in the 9-smooth model pile groups with different embedment length in dry sand

Condition of sand under pile base	**Condition of sand around piles**	**Pile spacing S**	**Embedment length Ld**	**Pp central pile KN**	**Pp Outside pile KN**	**Pp Corner pile KN**	**Pp central pile / Pp outside pile**	**Pp central pile / Pp corner pile**
Dense dry sand Dr = 0.93	*Medium Dense dry sand Dr* = 0.58	2.5*d*	0.38*L*	1.14	0.81	0,60	1.40	1.90
			0.65*L*	1.42	0.88	0.68	1.62	2.10
			0.93*L*	1..85	1.05	0.86	1.76	2.26
		4,2*d*	0.36*L*	0,81	0.64	0.58	1.27	1.39
			0.65*L*	1.0	0.85	0.76	1.17	1.31
			0.93*L*	1.38	1.11	0.91	1.24	1.52
Dense dry sand Dr = 0.93	*Dense dry sand Dr* = 0.84	2.5*d*	0.36*L*	1.70	1.14	0.84	1.49	2.02
			0.65*L*	2.70	1.79	1.35	1,56	2.07
			0.93*L*	3.32	2.33	1.47	1.43	2.26
		4,2*d*	0.36*L*	1.20	0.97	0.82	1.24	1.47
			0.65*L*	2.18	1.60	1.35	1.36	1.62
			0.93*L*	2.71	2.10	1.41	1.30	1.94

Table (3) The proportion of the base bearing capacity of individual piles in 9- smooth model pile groups in dry sand

Relative density of sand around piles Dr	**0.58**						**0.84**					
Pile spacing S	2.5*d*			4.2*d*			2.5*d*			4.2*d*		
Embedment length Ld	0.38*L*	0.65*L*	0.93*L*	0.38*L*	0.65*L*	0.93*L*	0.38*L*	0.65*L*	0.93*L*	0.38*L*	0.65*L*	0.93*L*
Pp central pile % / *Pp pile group*	16.8	18.6	19.5	14.3	13.4	14.6	17.7	18.2	17.9	14.4	15.6	16.3
Pp Outside pile % / *Pp Pile group*	12	11.5	11.1	11.2	11.4	11.8	11.8	11.5	11.1	11.6	11.5	12.5
Pp Corner pile % / *Pp pile group*	8.9	8.8	9.1	10.3	10.2	9.6	8.8	8ز8	8	9.3	9.7	8.4